THE USE OF PRESSURE-DIFFRENCE SAMPLERS IN MEASURING BEDLOAD TRANSPORT IN SMALL, COARSE-GRAINED ALLUVIAL CHANNELS

Sandra E. Ryan[1]

[1]USDA Forest Service, Rocky Mountain Research Station, Laramie, Wyoming (sryanburkett @fs.fed.us).

Keywords: bedload, pressure-difference samplers, weir ponds.

ABSTRACT

Pressure-difference samplers remain the most widely used devices for obtaining estimates of bedload transport in natural stream systems. This report describes some of these devices, citing the advantages and limitations of their use in small, coarse-grained alluvial channels. In a recent study, samples collected using three of these devices were tested to determine comparability. The rating curves were then integrated over flow records and the results compared with 31 years of annual accumulation collected from a weir pond. While there can be significant differences in the mass of material collected by different pressure-difference samplers, they generally produced data from which reasonable simulations of total accumulation could be derived.

INTRODUCTION

Defining rates of bedload transport in stream systems can be complicated because flows necessary for transporting larger particles are usually deep, turbid, and turbulent, making the direct physical measurement or visual observation of particle motion difficult. Difficulties are further compounded by erratic transport patterns, even under stable conditions of flow (Emmett, 1980; Gomez and Church, 1989). Developing representative sampling procedures in steep mountain channels is particularly problematic due to continually fluctuating flows, the presence of large roughness elements, and uneven bed topography. Yet, the need to understand channel process and patterns of coarse gravel transport requires that some effort to gauge bedload movement be undertaken, recognizing the limits of our present capability to measure the processes.

SAMPLER DESCRIPTIONS

Bedload movement is typically sampled using various traps, tracers, or samplers, including pressure-difference samplers. These devices consist of an open metal body with a front intake through which water and sediment pass and a flare that begins mid-body and expands to the back of the sampler (Figure 1). The flare causes pressure differences within the sampler and encourages deposition in an attached bag. While all pressure-difference samplers have this same basic configuration, different versions have openings and flares of varying sizes. Samplers are typically constructed of sheet metal, metal plates, or cast aluminum, which provide varying thickness to the walls. Several commonly used samplers are described in the following sections, but the listing is not an exhaustive one. All pressure-difference samplers may be hand-

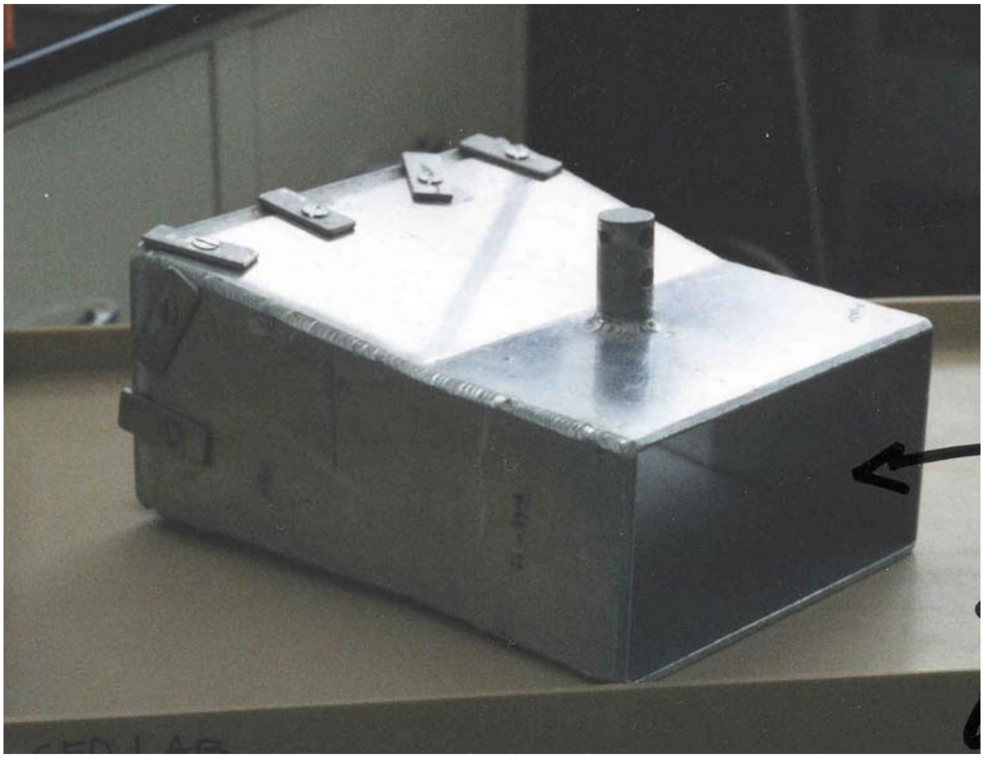

Figure 1. An example of a pressure-difference type bedload sampler. This particular device is a hand-held version (minus the handle and mesh sample bag) of an Elwha sampler (Childers et al., 2000).

held (Figure 2) and used while wading or from small bridges or suspended from cables and held in place using staylines.

Types of pressure difference samplers

The most commonly used pressure-difference sampler is the one described by Helley and Smith (Helley and Smith, 1971). The *original Helley-Smith* sampler is constructed of ¼ inch thick cast aluminum, with a 3 x 3 inch (inner dimension) intake, and an expansion ratio (flare exit area/entrance area) of 3.22. Since originally developed, a lighter, less expensive version has been manufactured commercially. This *GBC-type* (or sheetmetal) sampler is identical to the original, except for the material from which it is constructed (16 gauge stainless steel) and, hence, wall thickness. Because it is lighter and commercially available, this sampler has become a popular option for sampling transport of coarse sediment (sand to coarse gravel). Another frequently used sampler, particularly for high discharges, is the scaled-up version of the Helley-Smith. The *6 inch Helley-Smith* has the same expansion ratio and projected efficiencies as the original, but has an intake opening of 6 x 6 inches (Druffel et al., 1976). The cable version is usually constructed from a ¼ inch steel plate, while the wading version is constructed of 16 gauge stainless steel, making it lighter to handle. The advantage of the scaled-up sampler is that it can pass larger particles. However, the 6 inch sampler is considerably more difficult to place and hold on the bed and is relatively unsteady in high flows. As a result, the bed is more easily disturbed and substantially larger samples may be obtained from these devices (Ryan, USDA

Figure 2. Hand-held Elwha sampler in use at the Middle Fork Piedra River near Pagosa Springs, CO.

Forest Service, unpublished data). This effect is more pronounced at high flows, conditions under which the 6 inch Helley-Smith is usually deployed.

One early concern with the Helley-Smith was that the size of the flare and sampler construction seemed to affect local flow dynamics, causing the sampler to draw in more water (and, hence, sediment) than would pass through the same area without the sampler (i.e., the hydraulic efficiency). It was estimated that the hydraulic efficiencies associated with the Helley-Smith are about 1.54 (a hydraulic efficiency of 1 would mean the sampler has no effect on flow passage). A comparable sampler (*BLH-84*) was crafted that had an opening and wall thickness similar to the original Helley-Smith, but with a smaller flare (expansion ratio 1.4). The altered design causes it to have a smaller hydraulic efficiency (1.35) so it doesn't draw in water the way the original does (Hubbell et al., 1981). The reduced flare also makes it easier to fit the sampler into a rocky stream bottom.

While many pressure-difference samples have square openings, several newer models have a rectangular shape. The *Toutle River type 2* sampler, developed by Hydrologists at the USGS Volcano Observatory in Washington, has a 6 x 12 inch intake, a 1.4 expansion ratio, and is made from a 1/4" steel plate (Childers, 1999). The *Elwha* sampler is a scaled-down version of the Toutle River sampler, with a 4 x 8 inch opening and a similar flare and expansion ratio (Childers et al, 2000). Both the Toutle River and Elwha samplers are intended for use in streams with high rates of transport and large grains. In practice, we have found that the rectangular shape helps stabilize the larger sampler on the stream bottom, provided that there are few large grains to interfere with its placement. However, the increased size and mass do make the samplers more challenging to handle at high flows.

Advantages and limitations of pressure-difference samplers

The primary advantages of pressure-difference samplers is that they are portable and can be used at a number of different sites, from small, remote streams (hand-held versions) to larger rivers (cable-mounted versions). Depending on the configuration and sampling conditions, the samplers are relatively simple to use, but become more logistically challenging under increasing discharges. The sampling scheme can be designed to meet the objectives of different studies, whether the interest is in determining mean transport rates at-a-point (temporal variability) or variation in transport patterns over a cross-section (spatial variation). Databases may be developed within a single runoff season, depending on flow levels reached and sampled during the measurement period.

One limitation of the pressure-difference sampler is that the confidence in the estimate of mean transport may be low, for several reasons. A sample obtained from several positions within a cross-section is thought to represent a spatially and temporally averaged rate of transport that occurs over the course of 30 to 60 minutes. However, the actual amount of time the sampler is in contact with the bed during that time is relatively small. While it may take an hour to collect a bedload sample, the sampler is only on the streambed for about 20 minutes at different positions on the cross-section. The relatively low sampling intensity may cause the values from pressure-difference samplers to exhibit more variability than those measured using other techniques (Bunte et al., forthcoming). There is also a limit to the size of material that may be collected by a sampler with a relatively small opening, so estimates of flow competence based on these measurements may be suspect. However, most of the material moved as bedload under a wide range of flow is relatively small (sand and gravel). Grain size analyses of materials taken from a number of USDA Forest Service weir ponds indicates that 85% or more (by weight) of the grain sizes would pass easily into a sampler with a 3 x 3 inch opening (Wilcox et al., 1996). Hence, even small samplers are capable of measuring the majority of material moved as bedload in some systems. Finally, sampling procedures using pressure-difference samplers are highly labor intensive and, as such, can be quite expensive. In our experience, the cost to collect and analyze bedload samples for 1 site over 1 field season (about 30-40 samples) is about $25k.

Comparability of measurements between samplers and with estimates of annual accumulation

While rates of bedload transport are inherently erratic, variation in measurements has been attributed to factors other than the irregular nature of sediment delivery and transport processes. Specifically, there is concern that, due to slight modifications of design, similar types of pressure-difference samplers may collect substantially different amounts of sediment (Hubbell et al., 1987). To explore this further, a study was conducted that compared three similar models of pressure-difference samplers to test whether differences are statistically significant or whether sampler performance is so irregular and overlapping that one might regard them as being the same. The results confirm that the mass of samples collected by the devices can be significantly different (Ryan and Porth, 1999). On average, samples from an original Helley-Smith were about 1.5 times those from a BLH 84 and samples from a sheetmetal sampler were about 1.8 times those of an original Helley-Smith. The results of the former are similar to that of Hubbell et al. (1987) who found that the original Helley-Smith collected more material than BLH 84 and the results of the latter comparison are similar to Pitlick (1988) who found that the sheetmetal sampler collected about twice as much material as the original version. The overall implication is that measured transport rates will vary depending on the sampler used and, therefore, they are not directly comparable without some mode of calibration. However, our results also showed that flow is by far the most important element for predicting bedload transport, accounting for much of the variance in the analysis. The mean square error associated with discharge was 2-3 orders of magnitude greater than that associated with sampler type.

To place these finding in a larger context, sediment rating curves, determined from calculated transport rates and measurements of flow, were integrated over available flow records and compared with estimates of annual accumulation determined from surveys made at a weir pond below one of the collection sites. The long-term data from these weir ponds are among some of the best indexes available for such comparisons because each measurement is essentially a long-term average of bedload discharge (Ryan and Troendle, 1997). They therefore provide a standard for testing empirical and theoretical functions for bedload transport. Three estimates of annual yield, one for each device, were calculated for 31 years of flow record and compared against the annual accumulation from the pond. The results indicate that, despite differences

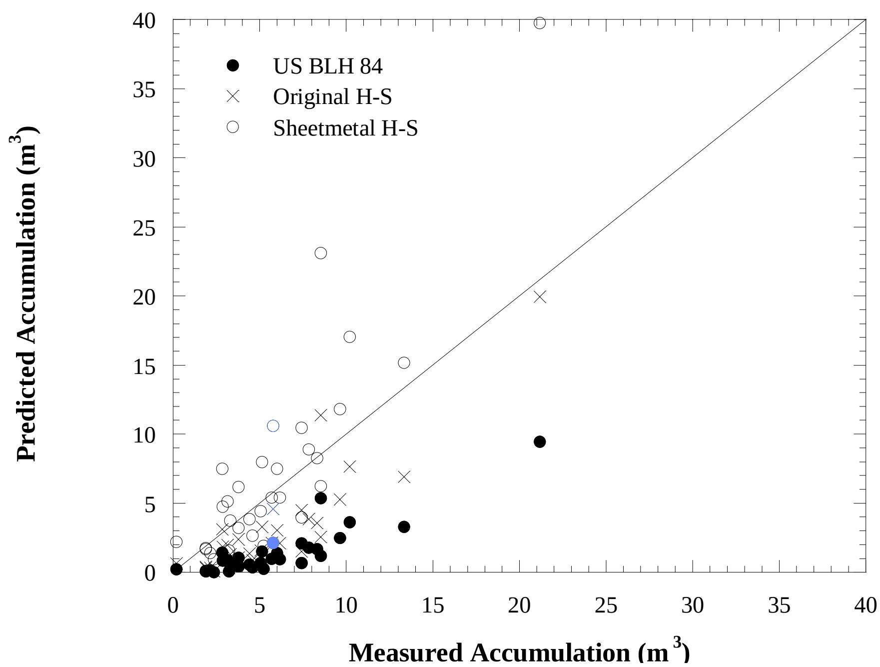

Figure 3. Comparison between predicted annual yield of sediment determined from rating curves based on data from 3 different types of pressure-difference samplers compared to annual accumulation measured in a weir pond on East. St. Louis Creek, Fraser Experimental Forest (n = 31). Symbols in blue represent data from 1996, the year this study was conducted.

between the devices, data obtained with pressure-difference samplers predicted annual accumulations reasonably well. Predicted accumulations were within 40-50% (on average) of the measured yield for the two Helley-Smith samplers while the BLH 84 predicted within 80% (Figure 3). Similar observations between predicted and measured accumulations have been made using data from other weir ponds (Troendle et al., 1996).

Comparability of grain sizes trapped with different samplers

It has been suggested that the sheetmetal Helley-Smith collects more sand-size grains relative to the original Helley-Smith sampler. While the specific mechanics behind this perception are unclear, it may be that the size of sediment relative to the thickness of the sampler wall affects the collection rates of different grain sizes. To test this, the amount of sand and gravel collected by the three pressure-difference samplers were compared to determine whether one or more grain sizes were preferentially trapped by any of the devices. If differences in the total mass of samples was due to bias within a given size fraction (e.g., sands), then one would expect to see significant differences for that fraction, but no detectable differences for other grain-size classes. Our results showed differences existed in each grain size class assessed (sand, fine gravel (2-8 mm) and coarse gravel (8-64 mm)) (Ryan and Porth, 1999). More material was collected by the sheetmetal Helley-Smith, less material was collected by the BLH 84, and the original Helley-Smith was intermediate between the two. The grain size distributions of a composite of all bedload samples was then compared against the grain size distribution acquired from the weir pond. It was assumed that because the bedload samples were obtained from the

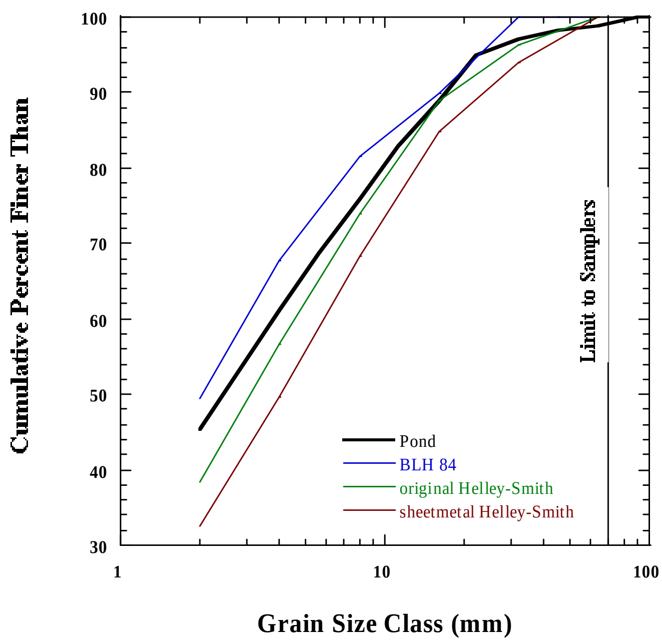

Figure 4. Cumulative distribution of grain-sizes measured in the weir pond in 1996 compared to the composite grain-size distributions collected by the three pressure-difference samplers.

entire high flow period, when the majority of sediment was moved, the grain size distributions for the three samplers and the ponds should be comparable. The results indicate that the distribution of grain sizes from the original Helley-Smith was the closest to that of the pond while the distribution from the sheetmetal sampler was slightly coarser (lies to the right) and the grains from the BLH 84 tended to be finer (lies to the left) (Figure 4). However, the predicted

D_{50} for all curves was between 2 and 4 mm (very fine gravel), suggesting that all four measurements provide a similar index to the grain sizes moved at this site during periods of high flow. Note that ninety-eight percent of the material (by weight) subsampled from the weir pond was small enough to pass through the opening of the 3 inch bedload samplers.

CONCLUSIONS

Pressure difference samplers are among the most commonly used devices for evaluating bedload transport in gravel bed channels. While there are several types in use, no one device has gained universal acceptance as the standard for use in all types of streams. Evidence suggests that similar devices may collect substantially different amounts of bedload with only slight modifications in design. The implication is that measured rates of transport will vary depending on the sampler used and, therefore, they are not directly comparable. Unfortunately, there is no means by which bedload data collected with different samplers can be calibrated directly. However, depending on the intended purpose, this may or may not be problematic. For instance, consistent use of one type of sampler would be critical if one is comparing mean rates of transport before and after management treatment because detectable differences in sediment could result from the sampling device alone instead of the treatment. Conversely, data from different samplers may be used in magnitude/ frequency comparisons because changing rates of transport with flow would be relative to the sampler used. The answer as to which flows move the majority of bedload at a site would be the same, provided that the same device is used for all measurements. The type of sampler used to make measurements should be provided as part of any bedload database so that a user may decide whether it is suited for particular purpose.

Despite the disparities and limitations associated with pressure-difference samples, comparisons between predicted yield and measured accumulations in a weir pond indicate that these devices produce data that can be used to reasonably simulate measured accumulations and, by extension, provide a good index to gravel transport processes in small, gravel bed streams. This is because the discharge (or other flow surrogate) explains a substantial amount of variance in rate of bedload transport and the effect of sampler type is small, by comparison. Because of this, data obtained from these samplers may be taken as first approximation of the true transport rate, in light of the current limitations on our ability to document bedload transport processes.

ACKNOWLEDGEMENTS

Funding for this work was provided by the Stream Systems Technology Center and the Rocky Mountain Research Station RWU 4352, USDA Forest Service, Ft. Collins, CO.

REFERENCES

Bunte, K., Abt, S.R., Potyondy, J.P., and Ryan, S.E. Forthcoming. Measurement of coarse gravel and cobble transport using a portable bedload trap. *Journal of Hydraulic Engineering.*

Childers, D., Kresch, D.L., Gustafson, S.A., Randle, T.J., Melena, J.T., and Cluer, B. 2000. Hydrologic data collected during the 1994 Lake Mills drawdown experiment, Elwha River, Washington. USGS Water Resources Investigation Report 99-4215. 115 p.

Druffel, L. Emmett, W.W., Schneider, V.R. and Skinner, J.V. 1976. Laboratory calibration of the Helley-Smith bedload sediment sampler. USGS Open-file Report 76-752. 63 pp.

Emmett, W.W. 1980. A field calibration of the sediment-trapping characteristics of the Helley-Smith bedload sampler. USGS Professional Paper 1139. 44 pp.

Gomez, B. and Church, M. 1989. An assessment of bed load transport formulae for gravel bed rivers. Water Resources Research 25:1161-1186.

Helley, E.J. and Smith, W. 1971. Development and calibration of a pressure difference bedload sampler. USGS Water Resources Division Open-file report. 18 p.

Hubbell, D.W., Stevens, H.H., Skinner, J.V., and Beverage, J.P., 1981. Recent refinements in calibrating bedload samplers. *In:* Water Forum '81. American Society of Civil Engineers, New York, 1: 128-140.

Hubbell, D.W., Stevens, H.H., Skinner, J.V., and Beverage, J.P., 1987. Laboratory data on coarse-sediment transport for bedload sampler calibration. USGS Water Supply Paper 2299.

Pitlick, J., 1988. Variability of bed load measurements. Water Resources Research 24(1):173-177.

Ryan, S.E. and Troendle, C.A. 1997. Measuring bedload in coarse-grained mountain channels: procedures, problems, and recommendations. *In:* Water Resources Education, Training, and Practice: Opportunities for the Next Century. AWRA Symposium, June 29- July 3, Keystone, CO. pp. 949-958.

Troendle, C.A., Nankervis, J.M. and Ryan, S.E. 1996. Sediment transport from small, steep-gradient watersheds in Colorado and Wyoming. *In:* Sedimentation Technologies for Management of Natural Resources in the 21st Century. Sixth Federal Interagency Sedimentation Conference, March 10-14, 1996, Las Vegas, NV. pp IX-39 -IX45.

Wilcox, M.S., Troendle, C.A., and Nankervis, J.M. 1996. Bedload transport in gravel bed streams in Wyoming. *In:* Sedimentation Technologies for Management of Natural Resources in the 21st Century. Sixth Federal Interagency Sedimentation Conference, March 10-14, 1996, Las Vegas, NV. pp VI-28-VI33.